Experimental, Numerical and Analytical Characterization of Slosh Dynamics Applied to In-Space Propellant Storage, Management, and Transfer

Completed Technology Project (2014 - 2016)

Project Introduction

Advancements in long term, in-space, cryogenic propellant storage and transfer science and technologies are key to increasing the safety, decreasing cost, and increasing payload mass of NASAs space missions. Of increasing concern are the effects of propellant slosh on spacecraft. Since propellant usually makes up a large portion of a spacecrafts mass, controlling the motion of it is extremely important. Unintended motion of the propellant, i.e. slosh, can have many negative effects on a spacecraft. Sloshing propellant can cause vapor ingestion into a rocket engine that results in catastrophic failure. Slosh induced from orbital maneuvers can cause unintended shifts in the vehicles trajectory and instability. Slosh can increase boil-off via droplets evaporating from contact with warm tank surfaces, increasing the pressure inside the tank and the chances of tank venting. Slosh can also cause fluid to be vented instead of the gas, which is not only wasteful, but dangerous; venting fluid can impart unexpected thrust to the vehicle and even cause the vents to freeze closed, potentially resulting in catastrophic tank over-pressurization. Slosh during transfer can affect the thermal state of the propellant and ullage, which may cause performance issues during tanking and detanking operations. In addition to the thermodynamic effects, slosh may have fluid dynamic effects on transfer (and vice versa). Thanks to recent advances in computational capabilities, accurate numerical modeling of slosh is now possible. Computational Fluid Dynamics (CFD) tools are critical to predicting slosh dynamics and finding ways to mitigate the above (and other) concerns. CFD programs are very complex and require extensive experimental validation before the results can be trusted. These CFD programs have been validated by experiments on the ground using water and oil and found to be quite accurate. However, in the absence of gravity, the physics change drastically and liquids behave differently. These programs have not been validated for cryogenic fluids in microgravity. I am proposing to modify various slosh experimental platforms for use with cryogenic liquid nitrogen (LN2) to gather data relevant to benchmarking and expanding CFD simulation tools to characterize slosh dynamics of cryogenic propellants in 1g, micro- and zero-gravity storage, transfer, and management applications. The slosh experimental platforms that I will modify for use with LN2 include ground-based, sounding rocket-based, and zero-g aircraft-based test apparatuses. Slosh-management devices and fluid transfer research will be conducted along with the pure slosh experiments. These apparatuses, once modified for cryogenic LN2, will then inherently (or with slight further modifications) be able to study boil-off, stratification, ullage collapse, and those phenomenas interactions with slosh. Avenues for unconstrained, 6 DOF, zero-g on-orbit slosh tests will also be explored. I will then improve and expand the current numerical slosh models using the results from those experiments. Because it is a supporting technology, the applications of the proposed research are numerous. Specific applications that could benefit from this research include propellant tanks, spacecraft, launch vehicles, on-orbit fuel depots, satellites, power reactant

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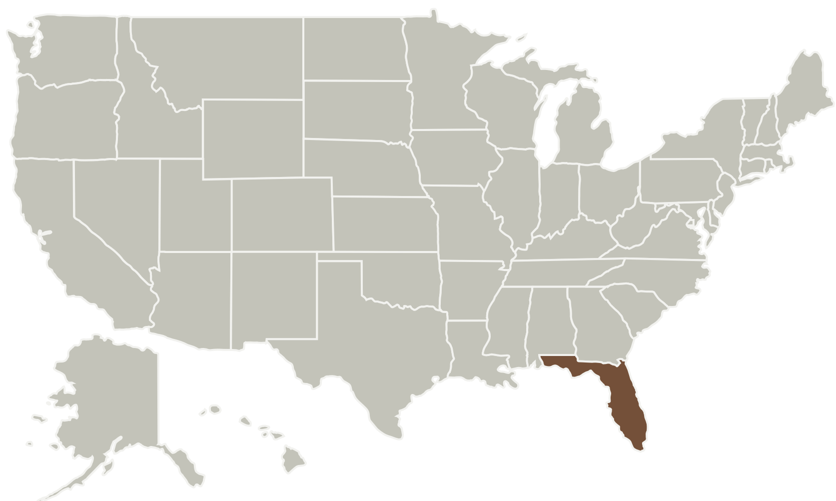
storage, and Environment Control and Life Support Systems (ECLSS). The models that will be improved and expanded by this research will give researchers, scientists, and mission planners improved confidence in their designs of these systems.

Anticipated Benefits

Because it is a supporting technology, the applications of the proposed research are numerous. Specific applications that could benefit from this research include propellant tanks, spacecraft, launch vehicles, on-orbit fuel depots, satellites, power reactant storage, and Environment Control and Life Support Systems (ECLSS). The models that will be improved and expanded by this research will give researchers, scientists, and mission planners improved confidence in their designs of these systems.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Florida Institute of Technology	Supporting Organization	Academia	Melbourne, Florida

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

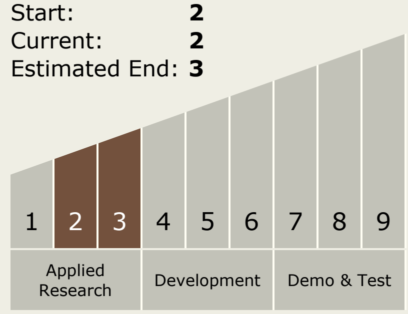
Daniel R Kirk

Co-Investigator:

Jedediah M Storey

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Primary U.S. Work Locations

Florida

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Areas

Primary:

- TX01 Propulsion Systems
  - └─ TX01.1 Chemical Space Propulsion
    - └─ TX01.1.1 Integrated Systems and Ancillary Technologies